Virtual Test Bed For Evaluating Wave Prediction Technology

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LONG-TERM GOAL

This contract supports a part of a larger program of applied research whose ultimate goal is to significantly improve our ability to predict ocean waves in deep and shallow water environments. That larger program is organized under ONR's Advanced Wave Prediction Program. The specific part of that program of which our effort is a part addresses the development of a "virtual test bed for evaluating wave prediction technology". This "test bed" project responds to the fact that there have been no significant advances in operational wave modeling and prediction since the introduction of the WAM model over a decade ago. The test bed is intended to stimulate scientists to systematically investigate, implement and test more advanced algorithms (source terms) which simulate wave growth, interaction and dissipative processes in deep and shallow water wave prediction models and to provide a rational objective framework to evaluate the efficacy of model enhancements.

This test bed program is a coordinated collaborative effort between scientists at Oceanweather Inc., the U.S. Army Corps of Engineers Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC), and the U.S. Naval Research Laboratory (NRL).

SPECIFIC OBJECTIVES

The specific objectives of Oceanweather's component of the test bed program may be succinctly stated as follows: (1) contribute to the identification and selection of the real historical scenarios to be used to populate the virtual test bed, taking into account at least the following: potential accuracy of wind inputs, suitability of bathymetry, availability and accuracy of measured wave data, spatial and temporal scales of the wave field; (2) for each selected case requiring post-analysis wind fields, develop the most accurate wind fields possible, given the available data base, using detailed kinematic reanalysis; (3) contribute to the assembly and processing of the measured wave data to be used to evaluate the wave model simulations: (4) contribute to the design of the statistical package to be developed for the test bed for objective model evaluations ; (4) contribute to the testing, evaluation and documentation of a prototype virtual test facility to be implemented at WES and NRL in anticipation of its transfer to other systems.

WORK COMPLETED

In FY1998, wind fields from various past projects were identified for inclusion into the virtual test bed (VTB). These wind fields include SWADE IOP-1, "Halloween Storm", "Storm of the Century", and 9

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tropical systems in the Gulf of Mexico and North Atlantic. In FY1999, these wind fields were collected and space interpolated onto test grids defined by the virtual test bed team.

There were several new wind field additions to the VTB, including Hurricane Danielle of 1998. Hurricane Danielle started as a tropical wave off of Africa in 21st of August and reached tropical storm strength by August 24th. The system had a long track in the North Atlantic, but did not seriously impact land. Peak intensity of 90 knots was attained on August 26th about 900 Nmi east of the Leeward Islands. Danielle's track took the system directly over the Canadian buoy array on September 3rd, passing very close to buoy 44141 (Laurentian Fan). The buoy reported a minimum pressure of 962.6 mb and significant wave height of 15.8 meters (26.8 meters, maximum wave height). This measurement, along with buoys 44137, 44120, 44138, 44251, 44144 and 44142 made Danielle an excellent candidate for the VTB. A hindcast was performed using all available in-situ data including buoys, ship reports, altimeter measurements, scatterometer measurements, and aircraft reconnaissance winds. As noted in figure caption this case promises to be very useful for testing new 3rd generation physics algorithms.

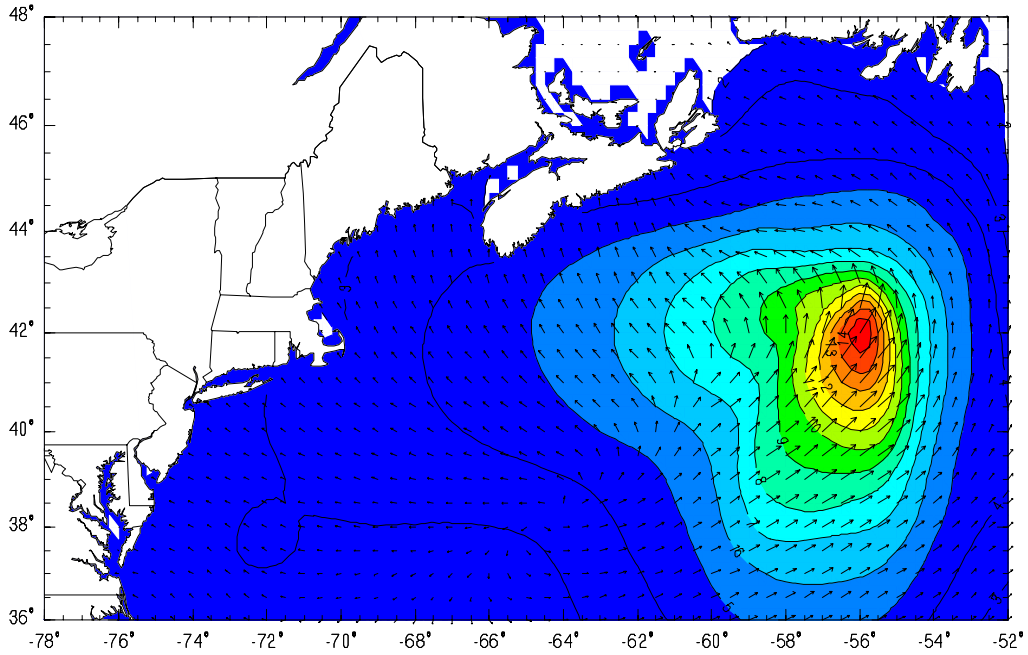

Figure 1. Wave hindcast of Hurricane Danielle (1998) as the system passed over Canadian buoy 44141 (Laurentian Fan) on September 3, 1998 at 9:00 GMT. Significant wave height (Hs) contours are every meter with arrows representing vector mean wave direction (to which). The maximum measured significant wave height was 15.8 meters that was closely matched by the hindcast. The budge in the Hs contours to the left of the track is indicative of a positive bias of hindcast Hs. Such a bias has also been seen in hindcasts of several other recent hurricane hindcasts made with 3rd generation models. Fast moving tropical cyclones, therefore, will provide a critical test of wave models in the VTB.

One of the requirements of the VTB was the development of a long-term continuous wave simulation to provide feedback to wave modelers on the performance of a particular wave model during non-storm "normal" conditions. As part of the Canadian sponsored 40-year North Atlantic Wind and Wave Climatology, NCEP/NCAR wind fields were kinematically reanalyzed which included resolving all tropical systems and strong extra-tropical systems. The continuous year of 1996 was selected since it included both the NSCAT and ERS-2 scatterometer winds for the best basin-wide coverage available.

Another of the goals of the VTB was to develop and explore ways of evaluating model output and measurements. During FY1999, the TIMESCAT (Cox *et.al.* 1999) program was expanded to produce comparisons of wave height, wave period, and wave direction against both fixed (such as buoys) and moving platforms (such as altimeter measurements). Figure 2 shows a wave height comparison made with the TIMESCAT program. It compares combined (ERS1/2 and TOPEX) altimeter waves against time/space matched model output.

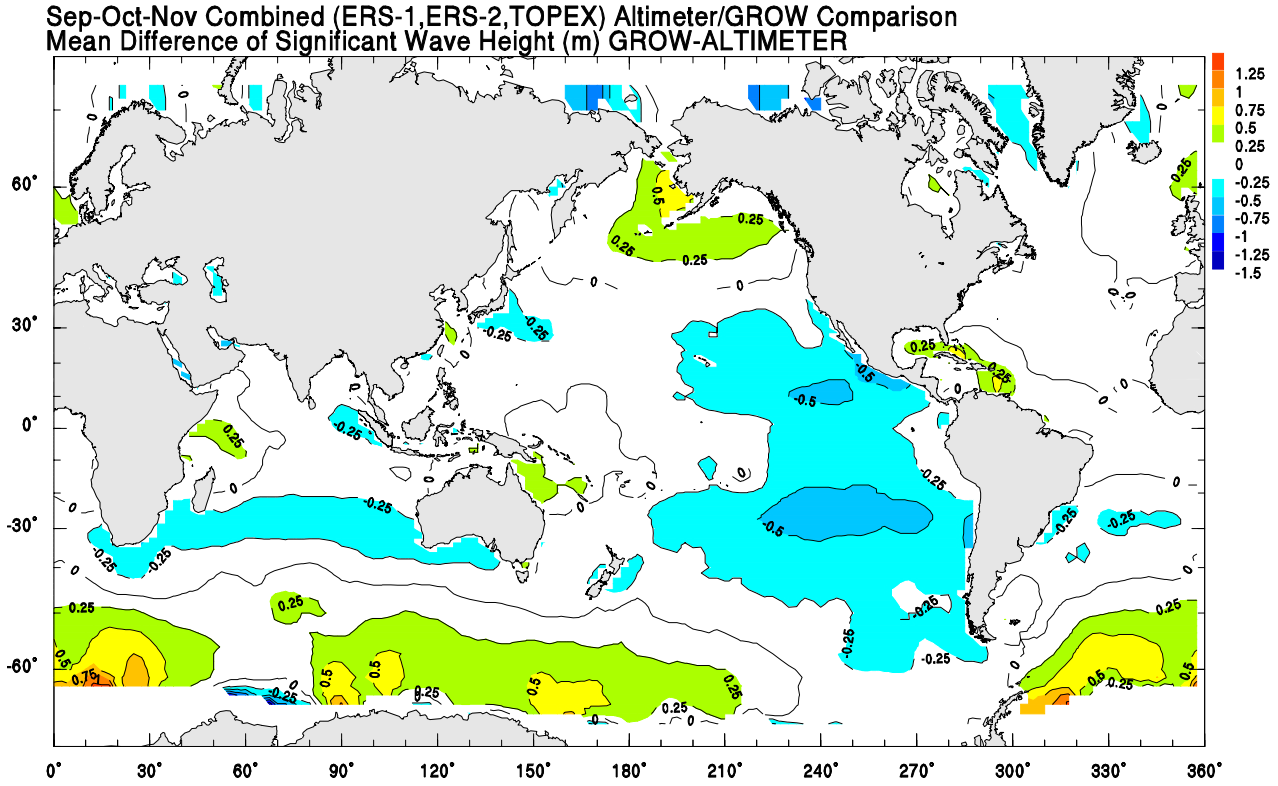

Figure 2. Comparison of wave hindcast significant wave height vs. combined ERS 1/2 and TOPEX altimeter wave measurements over the period 1991 though 1997 for the September/October/November months.

PLAN FOR NEXT CONTRACT PERIOD

At this point, there are several candidate wind fields that are under consideration for inclusion into the VTB database. They include Hurricanes Bret and Floyd (1999), SWADE IOP's 2 and 3, additional storms from the North Atlantic, North Pacific and Gulf of Mexico regions, as well as 1 year continous

hindcasts of the North Pacific and Gulf regions. A storm selection for North Atlantic and North Pacific concentrating on the U.S. East/West coasts for maximum verification data produced the following potential storm cases:

Wind Field:	7802		
Grid Domain:	US E Coast	**Dates:**	Feb 06 1978 00GMT to Feb 09 1978 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case prior to 1980. The low stalled off of Long Island, bringing NE winds to MA, RI, and nearby offshore areas and feet of snow.		
Wind Field:	8001		
Grid Domain:	US E Coast	**Dates:**	Jan 14 1980 00GMT to Jan 18 1980 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. It maintained a tight gradient while retrograding east of MD and NJ.		
Wind Field:	8210		
Grid Domain:	US E Coast	**Dates:**	Oct 24 1982 00GMT to Oct 28 1982 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. 8210 tracked close to the coastline, striking NC.		
Wind Field:	8302		
Grid Domain:	US E Coast	**Dates:**	Feb 10 1983 12GMT to Feb 14 1983 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. A smaller storm than 8210, 8301 remained over water while travelling from FL northward. The storm tightened and slowed as it passed Long Island and RI.		
Wind Field:	8303		
Grid Domain:	US E Coast	**Dates:**	Mar 24 1983 00GMT to Mar 27 1983 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Also emerged from FL but tracked more eastward, never making it as far north.		
Wind Field:	8403		
Grid Domain:	US E Coast	**Dates:**	Mar 28 1984 12GMT to Apr 01 1984 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. 8403 was a large storm entering the NAtl from DE.		
Wind Field:	8502		
Grid Domain:	US E Coast	**Dates:**	Feb 12 1985 00GMT to Feb 16 1985 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Only the periphery of 8502 affected the coastal waters, the center remained entirely inland.		
Wind Field:	8701		
Grid Domain:	US E Coast	**Dates:**	Jan 04 1987 12GMT to Jan 07 1987 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Another southern storm, 8701 tracked almost due east along 30° N.		
Wind Field:	8912		
Grid Domain:	US E Coast	**Dates:**	Dec 23 1989 00GMT to Dec 26 1989 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. 8912 remained offshore with a tight gradient to its west.		
Wind Field:	9212		
Grid Domain:	US E Coast	**Dates:**	Dec 10 1992 12GMT to Dec 14 1992 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		

Description:	An intense extratropical East Coast storm that provides an excellent test case. 9212 stalled over DE for about 18 hours and pounded NJ, Long Island, CT, RI, and MA.		
Wind Field:	9403		
Grid Domain:	US E Coast	**Dates:**	Mar 02 1994 00GMT to Mar 06 1994 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. 9403 tracked along the coastline, keeping its center over land from FL to MD before pushing out to sea.		
Wind Field:	9412		
Grid Domain:	US E Coast	**Dates:**	Dec 22 1994 00GMT to Dec 27 1994 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Developed a pair of lows where the northern one behaved like a hurricane.		
Wind Field:	9511		
Grid Domain:	US E Coast	**Dates:**	Nov 14 1995 00GMT to Nov 17 1995 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. 9511 tracked due north along 75° W.		
Wind Field:	9601		
Grid Domain:	US E Coast	**Dates:**	Jan 07 1996 00GMT to Jan 11 1996 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Similar to 8403.		
Wind Field:	9603		
Grid Domain:	US E Coast	**Dates:**	Mar 11 1996 00GMT to Mar 15 1996 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical East Coast storm that provides an excellent test case. Remained completely offshore as it tracked in between two highs.		
Wind Field:	8212		
Grid Domain:	US W Coast	**Dates:**	Nov 29 1982 00GMT to Dec 03 1982 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. The observed waves were caused by a low over Nevada whose gradient reached into the Pacific.		
Wind Field:	8301		
Grid Domain:	US W Coast	**Dates:**	Jan 24 1983 00GMT to Jan 28 1983 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. 8301 formed out of a parent low in the Gulf of Alaska and tracked north along the OR and WA coastlines.		
Wind Field:	8303		
Grid Domain:	US W Coast	**Dates:**	Feb 28 1983 00GMT to Mar 05 1983 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Had a very long period - about 20 s - and affected CA.		
Wind Field:	8312		
Grid Domain:	US W Coast	**Dates:**	Dec 01 1983 00GMT to Dec 05 1983 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Struck southern most CA after tracking due east along 32° N.		
Wind Field:	8402		
Grid Domain:	US W Coast	**Dates:**	Feb 23 1984 00GMT to Feb 26 1984 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. With a large circulation, 8402 traveled almost due east before crossing into WA.		

Wind Field:	8411		
Grid Domain:	US W Coast	**Dates:**	Nov 01 1984 00GMT to Nov 04 1984 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. 8411 remained offshore due west of the U.S./Canadian border allowing for strong westerlies to build over an extensive area offshore OR and WA.		
Wind Field:	8712		
Grid Domain:	US W Coast	**Dates:**	Dec 15 1987 00GMT to Dec 18 1987 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. 8712 deepened rapidly offshore northern CA then filled gradually as it tracked south.		
Wind Field:	8801		
Grid Domain:	US W Coast	**Dates:**	Jan 17 1988 00GMT to Jan 20 1988 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Similar to 8712, 8801 maintained its intensity for about 12 hours before tracking into southern CA.		
Wind Field:	9001		
Grid Domain:	US W Coast	**Dates:**	Jan 29 1990 00GMT to Feb 02 1990 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. A series of lows dropped out of the Gulf of Alaska bringing fierce NW winds to OR and WA.		
Wind Field:	9201		
Grid Domain:	US W Coast	**Dates:**	Jan 29 1992 00GMT to Feb 02 1992 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Similar to 8301 except it remained farther offshore.		
Wind Field:	9512		
Grid Domain:	US W Coast	**Dates:**	Dec 10 1995 00GMT to Dec 16 1995 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Formed and tracked similar to 8301.		
Wind Field:	9711		
Grid Domain:	US W Coast	**Dates:**	Nov 18 1997 00GMT to Nov 21 1997 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. 9711 slowly approached the U.S. West Coast before curving to the north and crossing onto land near the WA/Canadian border.		
Wind Field:	9802		
Grid Domain:	US W Coast	**Dates:**	Feb 02 1998 00GMT to Feb 09 1998 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Similar to 8301 in formation and track, 9802 remained farther to the south. Another low followed the same path only 3 days later.		
Wind Field:	981124		
Grid Domain:	US W Coast	**Dates:**	Nov 22 1998 12GMT to Nov 27 1998 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Similar to 8301, except it crossed onto land near the WA/Canadian border on the 24th. Later that same day, another bigger low approached from the NW, its gradient reaching all the way to northern CA while is center remained due west of the U.S./Canadian border.		
Wind Field:	981130		
Grid Domain:	US W Coast	**Dates:**	Nov 28 1998 00GMT to Dec 03 1998 00GMT
Source:	Kinematic Analysis (6 Hourly, .5 degree)		
Description:	An intense extratropical West Coast storm that provides an excellent test case. Formed and tracked similar to 9802		

Additional work for FY2000 also involves extending the TIMESCAT program to 2-D spectra comparisons. Comparisons under consideration at this time include integrated direction, spectral width, and various sea/swell partitioning methods such as Oceanweather's algorithm, JONSWAP-Torsethangen, and Gerling's method.

PUBLICATIONS

Cox, A.T., V.J. Cardone and V.R. Swail, 1999: On the Use of In Situ and Satellite Wave Measurements for Evaluation of Wave Hindcasts. CLIMAR 99 Preprints, 8-15 September, 1999, Vancouver, Canada.

Resio, D.T., V.R. Swail, R.E. Jensen and V.J. Cardone, 1999: Wind Speed Scaling in Fully Developed Seas. JPO Vol 29, pp 1801-1811.